

Multipole analysis of kaon photoproduction data

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Methods used in the multipole analysis of low-energy pion photoproduction data have been tested against the database of kaon photoproduction measurements. Results for some multipoles are in qualitative agreement with existing phenomenological models, while others are unstable, given the present database. These findings are compared to those of previous studies.

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I. INTRODUCTION

The study of kaon photoproduction is motivated by the possibility of a model-independent amplitude reconstruction [1]. This type of analysis has been realized for nucleon-nucleon scattering [2] and may soon be attempted for kaon photoproduction, given the existing and expected data for single- and double-polarization quantities. A second motivation hinges on the possibility that a resonance analysis will reveal states not clearly seen in processes containing initial or final single-pion states. Several recent [3, 4] and older [5, 6] studies have noted that these two goals (amplitude reconstruction and multipole analysis) are very different in nature. In the following, we have applied the method used in Ref. [4] to the low-energy kaon photoproduction database in order to do a multipole analysis.

In Ref. [4], the low-energy pion photoproduction database was analyzed using a two-step procedure. Charged-pion photoproduction data were fitted assuming a known t-channel pion exchange mechanism for the high (unfitted) multipoles. This effectively removed the overall phase ambiguity that arises when only a finite number of multipoles are fitted, and the higher waves are neglected. The obtained charged-pion multipoles, and an application of Watson's theorem [7] for multipoles coupled to the elastic P_{33} πN partial wave, allowed for the determination of neutral-pion production multipoles. In a similar approach, not using Watson's theorem directly, Grushin [5] was able to extract the πN phases from a fit to photoproduction data.

As charged-kaon photoproduction has a t-channel process contributing to high partial waves, the method used in Ref. [4] was applied over a region where s - and p -wave multipoles were expected to dominate. We have focused on energies from threshold to 1.8 GeV in center-of-mass energy (W_{CM}), as this covers a region influenced by the $N(1650)S_{11}$, $N(1710)P_{11}$, and $N(1720)P_{13}$ resonances, included in the kaon MAID fit, but is below the proposed $N(1900)D_{13}$ [8, 9].

The t-channel process in kaon photoproduction is generally [8, 9] built up from the exchange of the K^+ , $K^*(892)$, and $K^*(1270)$. The latter two states have sizeable widths producing complex multipoles. The contri-

bution to the total cross section from Born plus K^* exchange diagrams is known to increase rapidly at moderate energies and this feature is usually handled with the introduction of form factors [10]. As a result, the prediction of higher multipoles is more model-dependent here than in the case of charged-pion photoproduction.

We should also note that a recent single-energy multipole analysis has found broad bands of multipole solutions, which are experimentally indistinguishable, using the existing database [11]. Our findings are slightly more optimistic, showing at least qualitative agreement with some previous phenomenological fits. Problems noted in Ref. [11] have been found here as well.

II. FITTING THE DATA

Data were fitted at single energies corresponding to the low-energy measurements of P , Σ , T , O_x , and O_z from the GRAAL collaboration [12]. Differential cross sections were taken from the CLAS collaboration [13]. The lowest energy point from Ref. [12] was omitted, as contradictory differential cross section measurements exist just above and below this energy. Conventions for the signs of polarization measurements were taken from Ref. [3, 14], differing from those adopted in Ref. [11].

In fitting the data, multipoles up to E_{2-} and M_{2-} were varied. Waves beyond those being fitted were taken from the Born plus K^* exchange diagrams used in the kaon MAID fit [8, 9]. In practice, however, over the considered energy range, the E_{2-} and M_{2-} multipoles were found to be compatible with the Born contribution, apart from contributions to the real parts of E_{2-} and M_{2-} . The resulting values for chi-squared per degree of freedom were between 0.5 and unity for all searches.

In Fig. 1 we show the quality of our fit to the cross section, P , Σ , and T data, corresponding to lab photon energy of 1027 MeV ($W_{cm}=1675$ MeV). Figure 2 shows the fit to O_x data and a prediction of O_z , C_x , and C_z . Fitting O_z and predicting the remaining observables gives a comparable result. The results in Fig. 3, for beam-target quantities E, F, G and H, are predictions. Preliminary CLAS data for E [15] show agreement with this behavior, but rather poor agreement with other previous analyses.

The level of agreement, only slightly worse than a fit of all observables, provides a validation of the method. However, the problem of uniqueness for extracted multipoles, found in Ref. [11], still persists.

III. MULTIPOLES

In Fig. 3, a set of single-energy multipoles is compared to the kaon MAID solution. The agreement is surprisingly good, particularly for the imaginary parts, which appear qualitatively consistent with the N(1650) and N(1710) resonances contained in kaon MAID. The behavior of E_{1+} is also evidence for a contribution from the N(1720). However, the M_{1+} multipole has a large real part not included in kaon MAID. A feature quite similar to this is seen in the energy-dependent multipole analysis of Mart [9]. A large near-threshold value, with a different sign, is also found in the Bonn-Gatchina analysis [16].

In Fig. 3, the multipoles at a particular energy were obtained through searches in parameter space near adjacent-energy solutions. However, in expanding the parameter space, we found indistinguishable solutions, with very low chi-squared, corresponding to different multipole sets. Results for the E_{1+} and M_{1-} were not stable. However, the trend seen in the E_{0+} and M_{1+} multipoles remains in these alternate solutions. Similar difficulties were also found in the multipole analysis of Ref. [11].

In Fig. 4, we show the dominant multipoles fitted up to 1.9 GeV. The fit remains quite good, retaining a chi-squared per degree of freedom less than unity, without requiring a search of higher multipoles. The real part of the M_{1+} multipole shows a rapid drop to zero, associated with a rise in the imaginary part, at approximately 1.9 GeV. This supports the claim for a 2-star N(1900) contribution [16].

IV. CONCLUSIONS

We have performed an exploratory single-energy multipole analysis of kaon photoproduction data near threshold - a region where we assumed only a few multipoles would deviate from Born predictions. The results are mixed. We have been able to fit a minimal set of data, predicting other observables, thus testing the method. However, a unique set of multipoles was not found. This confirms the findings of Ref. [11] with a somewhat different method.

Clearly, the validity of this method rests on the model-independence of the t-channel process. It would be useful

to repeat these fits with a set of different models for this contribution. Many recipes exist to moderate the Born contributions. Their effect is likely to add another source of model-dependence with increased energy. The fact that our search tended to require corrections to the real parts of the E_{2-} and M_{2-} multipoles suggests that a modified t-channel contribution may be required. This issue is presently being studied. Numerical values for the single-energy solutions and included datasets will be provided through the SAID webpage [17].

Plots of the extracted multipoles show qualitative similarities to the kaon MAID fit in some cases near threshold. For the M_{1+} , however, the result is qualitatively different near threshold, with resonance-like behavior near the N(1900) resonance energy.

In Ref. [11], multiple solutions were also found in fits to a larger set of observables, with a low chi-squared. Multipoles up to $L=3$ were searched, whereas we have taken waves with $L>1$ to be given by the Born contribution, including K^* exchange, with corrections to the real parts of E_{2-} and M_{2-} contributions found necessary in the fit. Fitting higher multipoles decreases the chi-squared but also reduces the Born contributions, which serve to remove the overall phase ambiguity. We have also found that including the E_{2-} and M_{2-} multipoles in the fit, when not required, tended to increase the uncertainties on the other fit parameters.

Multipole analyses come in two main types: those with a significant t-channel component, which is taken as known to remove the overall sign ambiguity (such as π^+n photoproduction), and others with a negligible t-channel contribution (such as π^0p photoproduction at low energies). In the latter case, one is free to fix one multipole phase and determine multipoles only up to this unknown phase (which is a function of energy). In Ref. [11], Born terms were added and a phase for the E_{0+} multipole was chosen. This was not done in the present fit. Here the Born contribution has fixed our overall phase and therefore the phase of E_{0+} as well.

We conclude by emphasizing that these single-energy multipole analyses are limited both by data quality and our confidence in the high angular momentum component.

Acknowledgments

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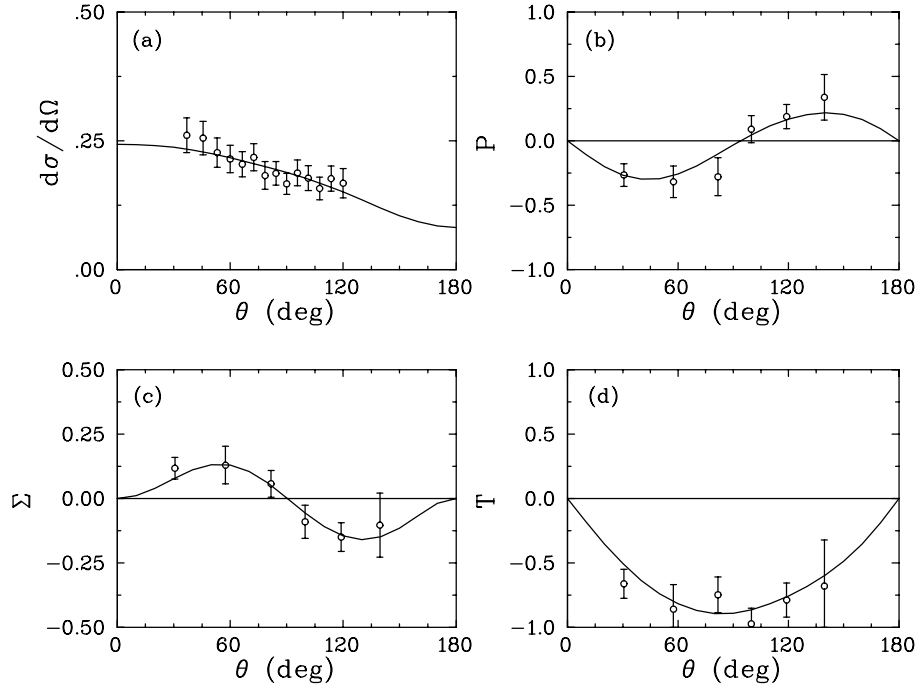


FIG. 1: Fit to $\gamma p \rightarrow K^+ \Lambda$ data: $d\sigma/d\Omega$ (a), P (b), Σ (c), and T (d) for $E_\gamma=1027$ MeV. Data from Refs. [12, 13].

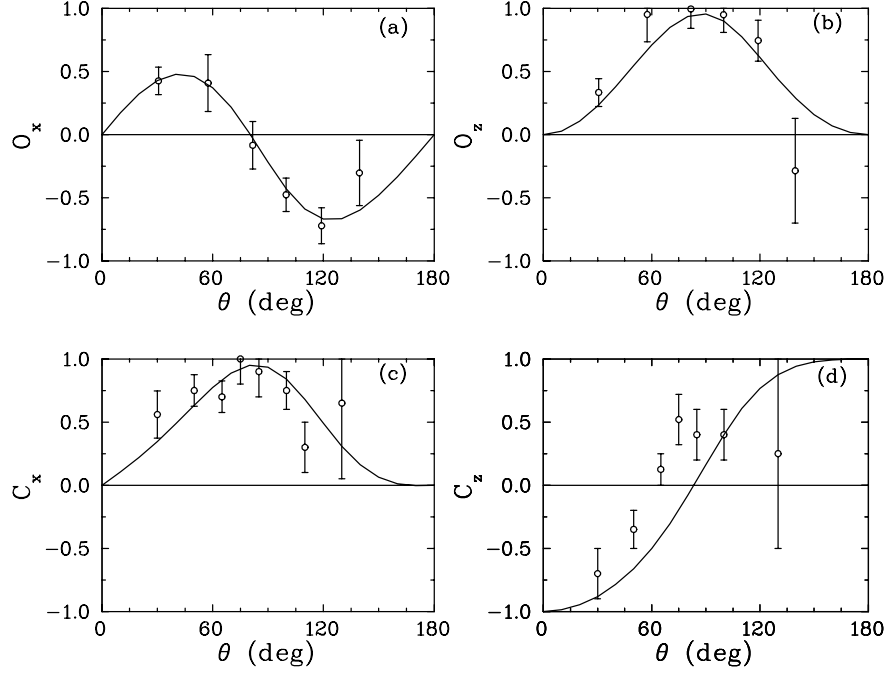


FIG. 2: Fit to $\gamma p \rightarrow K^+ \Lambda$ data O_x (a), and predictions for O_z (b), C_x (c), and C_z (d) for $E_\gamma=1027$ MeV. Data from Refs. [11, 12].

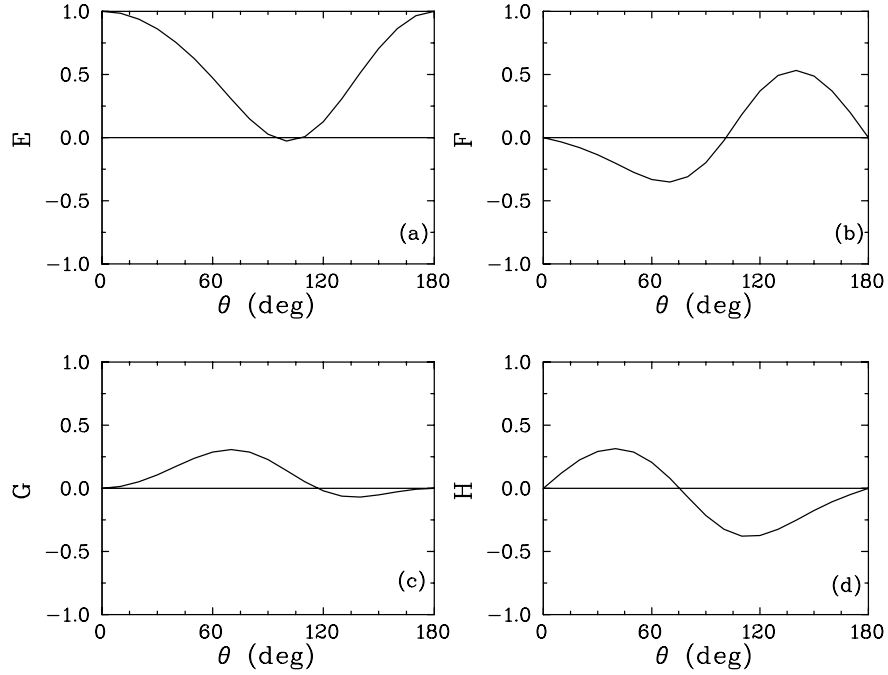


FIG. 3: Predicted $\gamma p \rightarrow K^+ \Lambda$ data E (a), F (b), G (c), and H (d) for $E_\gamma=1027$ MeV.

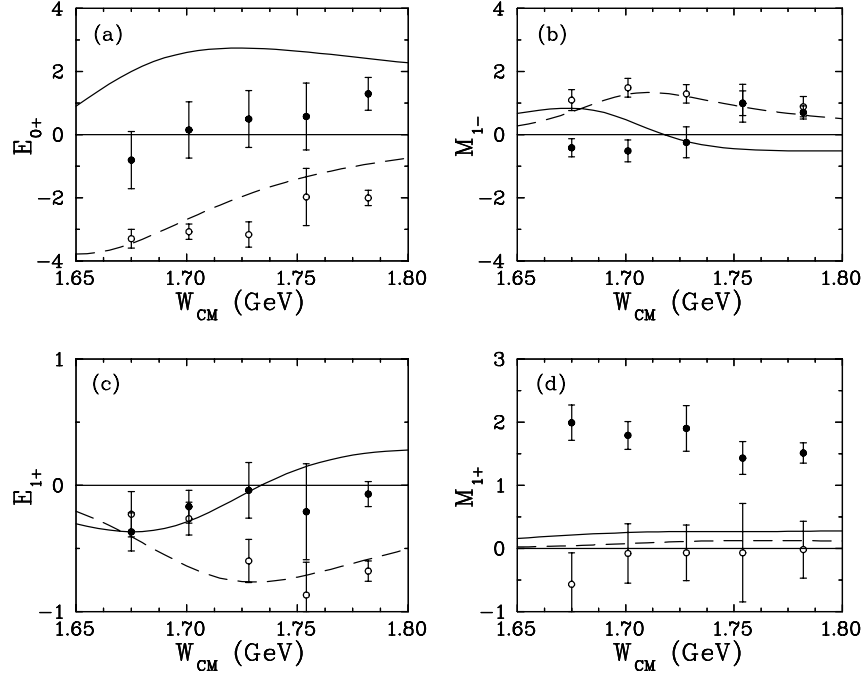


FIG. 4: Single-energy multipoles E_{0+} (a), M_{1-} (b), E_{1+} (c), and M_{1+} (d). Solid points correspond to real parts and open points give the imaginary parts of single-energy fits. Curves, solid (real) and dashed (imaginary), are given by the Kaon MAID solution. Units are $10^{-3}/m_{\pi^+}$.

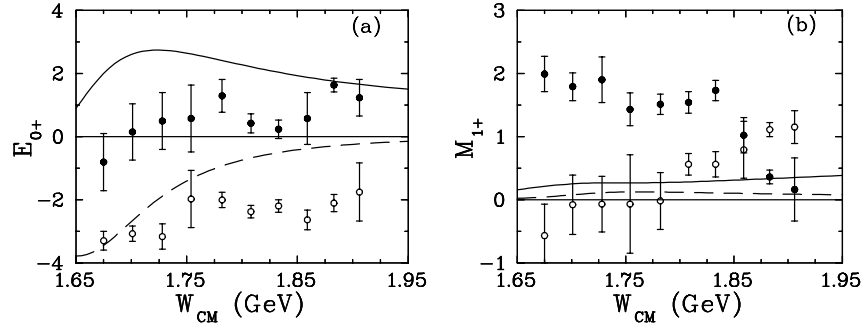


FIG. 5: Single-energy multipoles, E_{0+} (a) and M_{1+} (b), extended to 1.9 GeV. Notation as in Fig. 4. Units are $10^{-3}/m_{\pi^+}$.